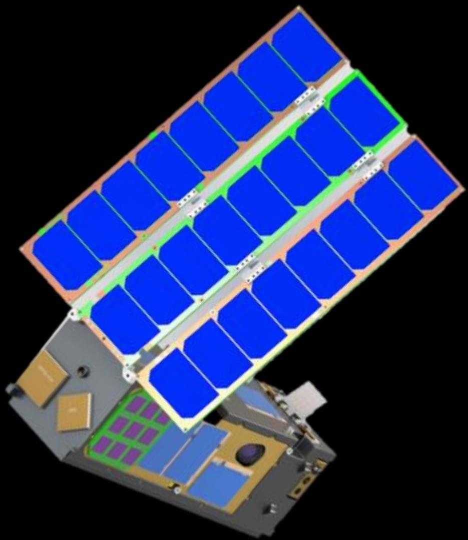
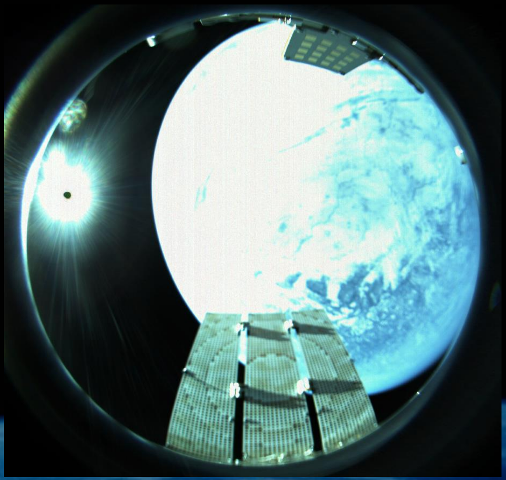
Results of ISARA On-orbit Operations and Validation Experiment
(Integrated Solar Array and Reflectarray)



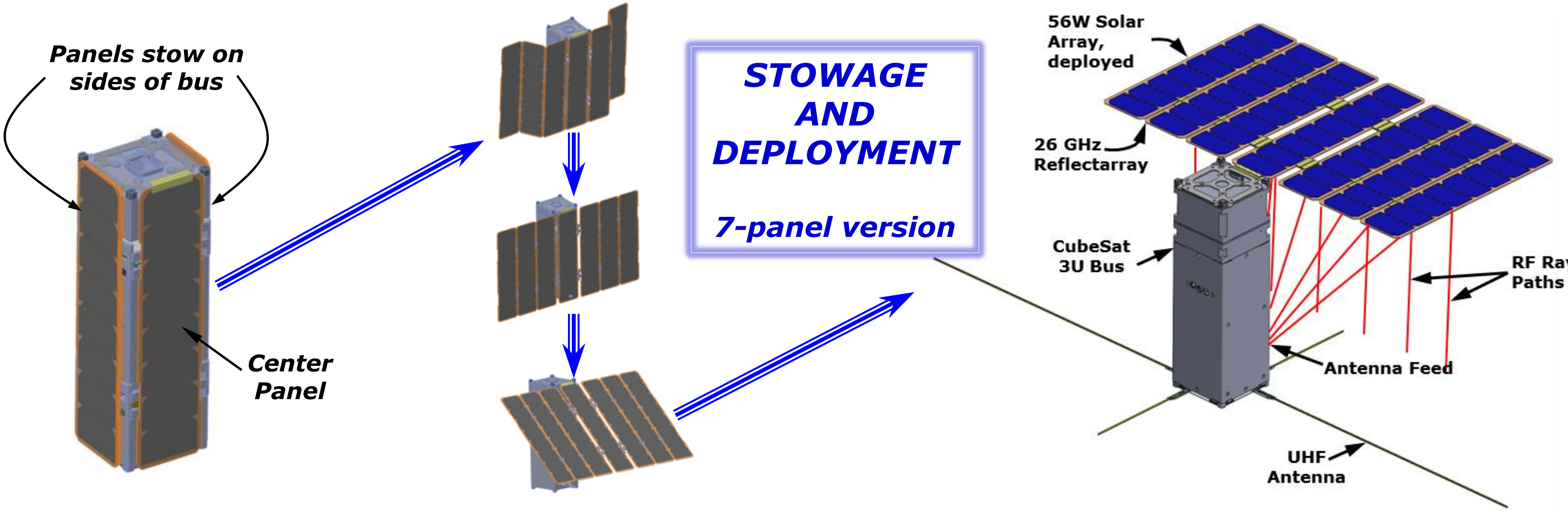
10th GFCS
May 9, 2018
Chantilly, Virginia



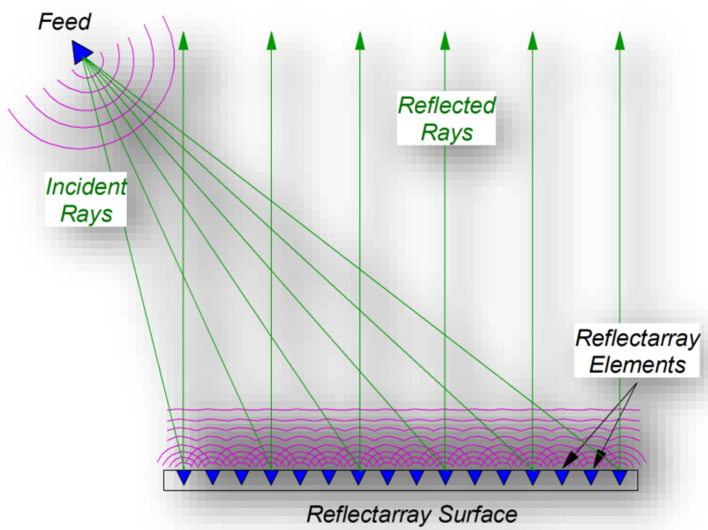
Richard Hodges, PI
Dorothy Lewis, PM
Andrew Gray
Tom Cwik
Jet Propulsion Laboratory, California Institute of Technology.

Darren Rowen
Rich Welle
The Aerospace Corporation

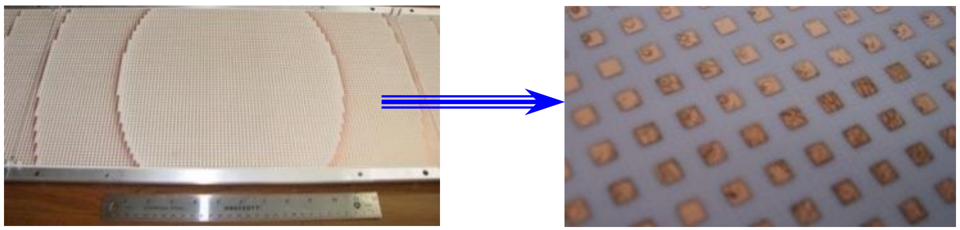
ISARA Concept – In a Nutshell

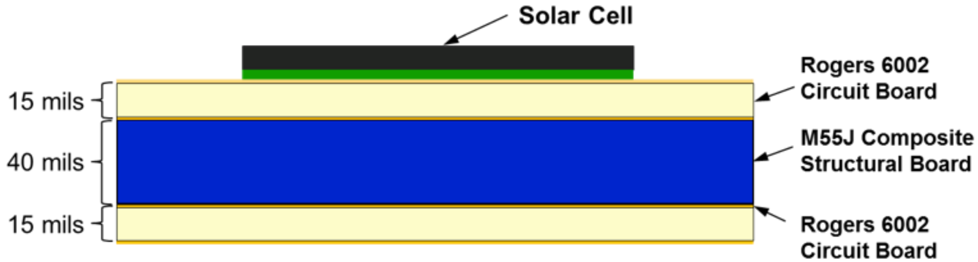


HOW A REFLECTARRAY WORKS



WHAT THE PANELS LOOK LIKE



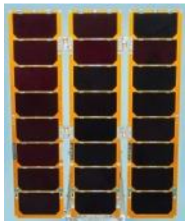


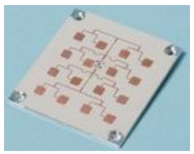
Printed Circuit Board Technology

ISARA as a System

Payload

Solar array/
Reflectarray
Antenna





SGA
Antenna

KB Exciter
Board

KBA
Feed

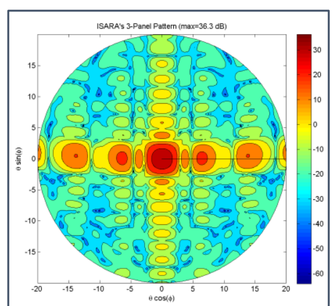
Integrated ISARA
Flight System

Pointing System
TT&C System
Power System

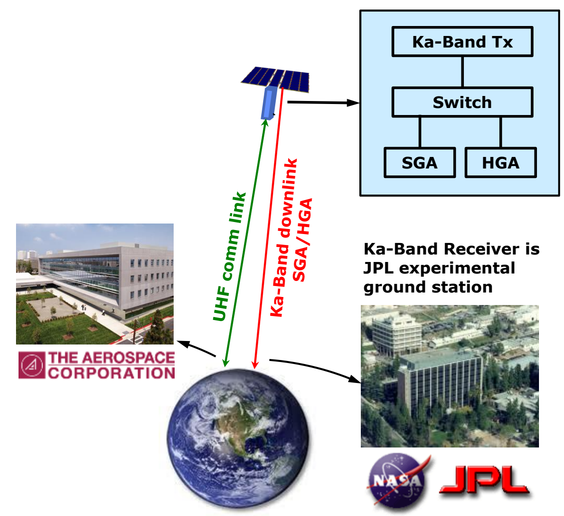
Spacecraft Bus - Aerospace

ISARA
being
loaded into
Dispenser

Secondary
Launch on
Orbital-ATK
Antares



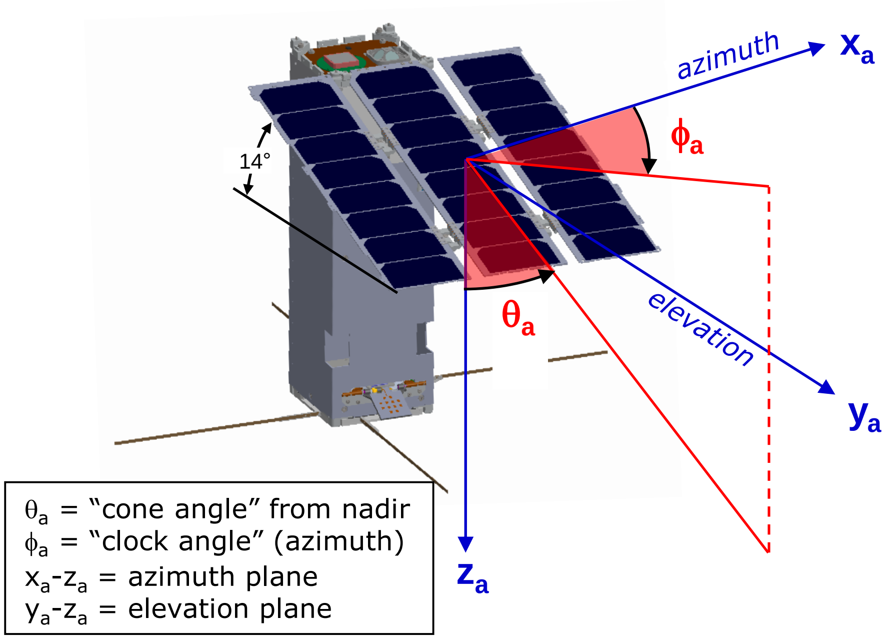
Measured
Antenna Pattern

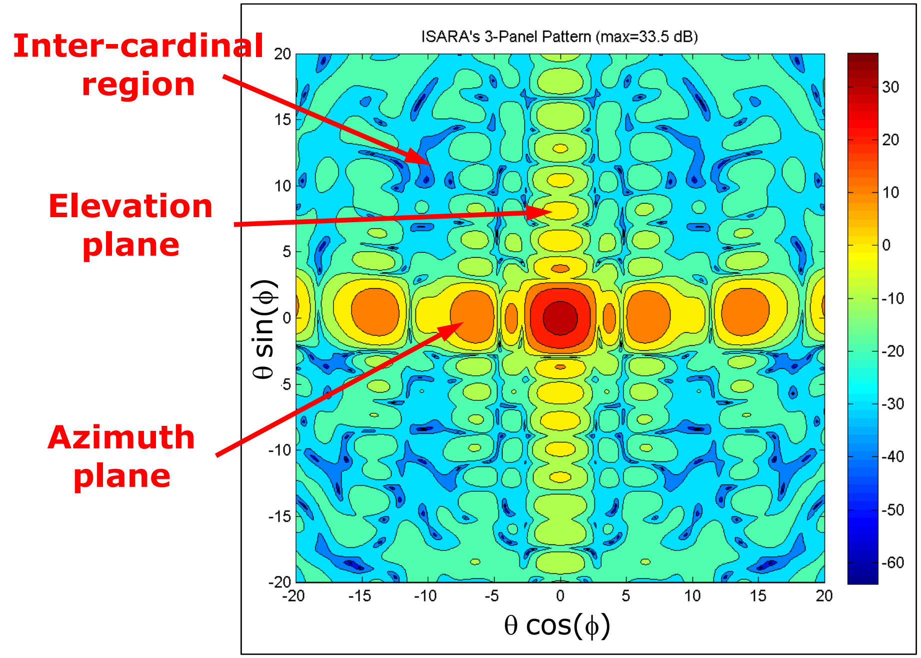


Tech Development - Level 1 Requirements

No.	Requirement	Verification Status
L1-1	The ISARA project shall measure the performance of a high-gain Ka-Band reflectarray antenna integrated with a solar array on a 3U CubeSat structure in a laboratory environment, and compare the results with those predicted by an antenna performance model.	✓ Completed reflectarray test ✓ Compared results to calculated ✓ EM and FM antenna in agree with model predict and meet performance requirements
L1-2	The ISARA project shall measure the performance of a high-gain Ka-Band reflectarray antenna integrated with a solar array on a 3U Cubesat in an operational environment.	✓ Completed FM antenna with solar array ✓ Draft Experiment plan complete ✓ Launch complete ✓ 3U CubeSat developed ✓ ADACS system achieves beam pointing ✓ Measured on-orbit gain per experiment plan
L1-3	The technology advances that result from the ISARA project shall be made available for commercialization.	✓ Pumpkin, STABLCOR, MMR developed capability to build ISARA panels ✓ Develop commercialization plan
L1-4	The ISARA project shall demonstrate that the Ka-band reflectarray antenna supports 100 Mbps peak data rate from low Earth orbit via link budget analysis and measured relative antenna gain.	✓ Developed detailed link budget that shows 100 Mbps capability ✓ Measured on-orbit gain verifies 100Mbps capability in link budget

Antenna Measurement Goals



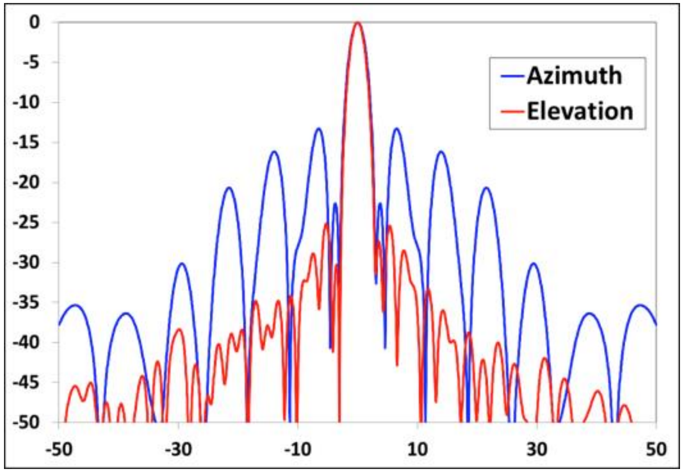


L1 Requirement: Measure Antenna Gain

- Validate 100 Mbps data rate
- Demonstrate operational telecom capability

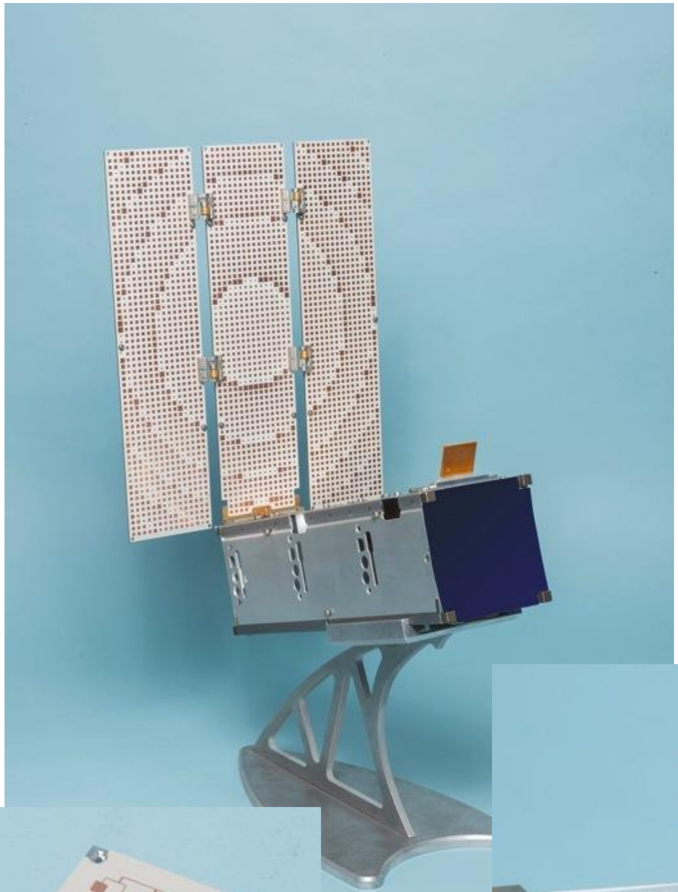
Secondary goal: Measure Antenna Patterns

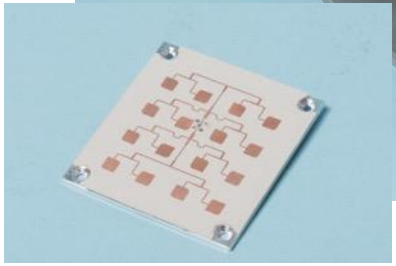
- Verify beam pointing accuracy
- Verify quality of antenna deployment

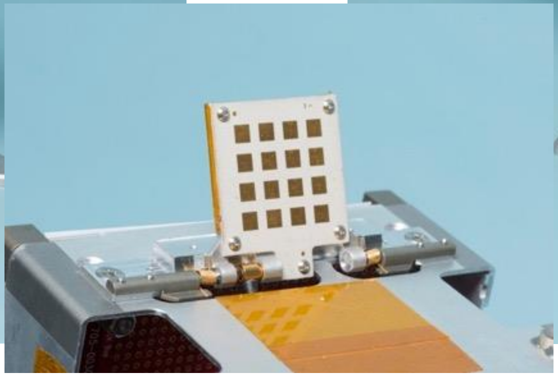


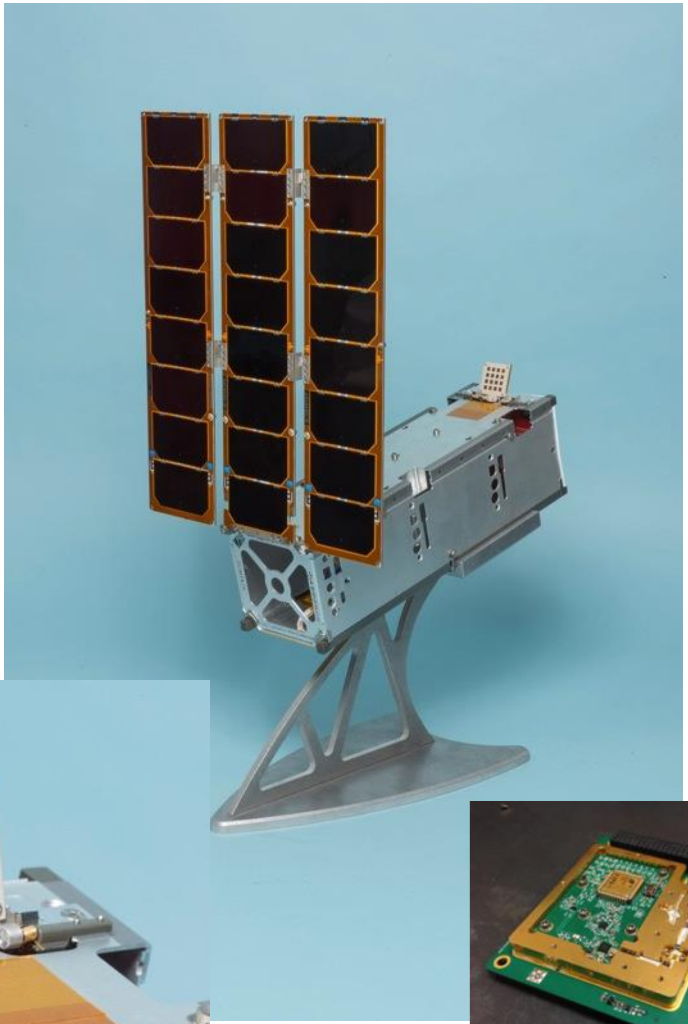
Principal Plane Patterns

Payload

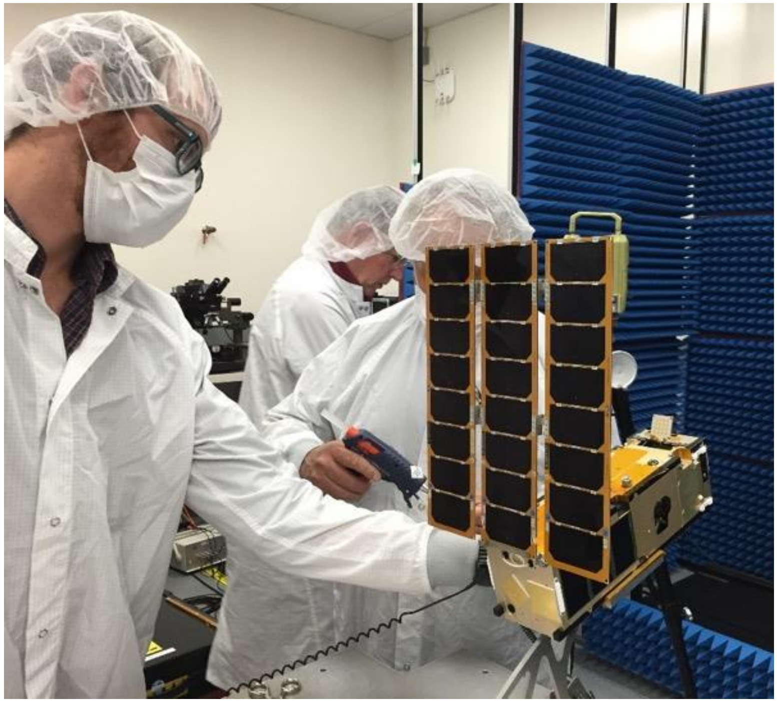








System Ground Test



At The Aerospace Corporation

Full S/C at JPL in Functional Test

ISARA Postlaunch Timeline

ISARA

11/12/2017 Antares rocket lifted off at 7:19 a.m. EST.

12/06/2017 Successfully deployed from ISS to an altitude of 452 km.

12/27/2017 ISARA array assembly successfully deployed. Received photos that confirm the reflectarray is fully deployed.

12/29/2017 Power system anomaly – failure of one of the two charging circuits; battery 1 of the two EPS-H batteries not charging.

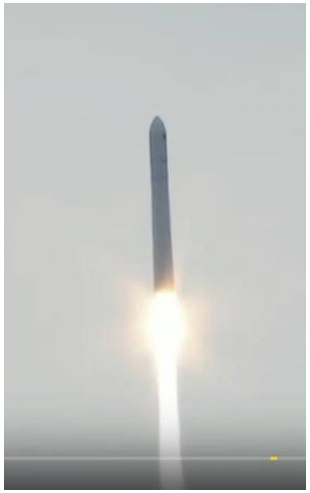
02/03/2018 TAC completes spacecraft checkout milestone list – all major s/c functions now regarded as operating nominally.

02/06/2018 Clear Ka-band signal received

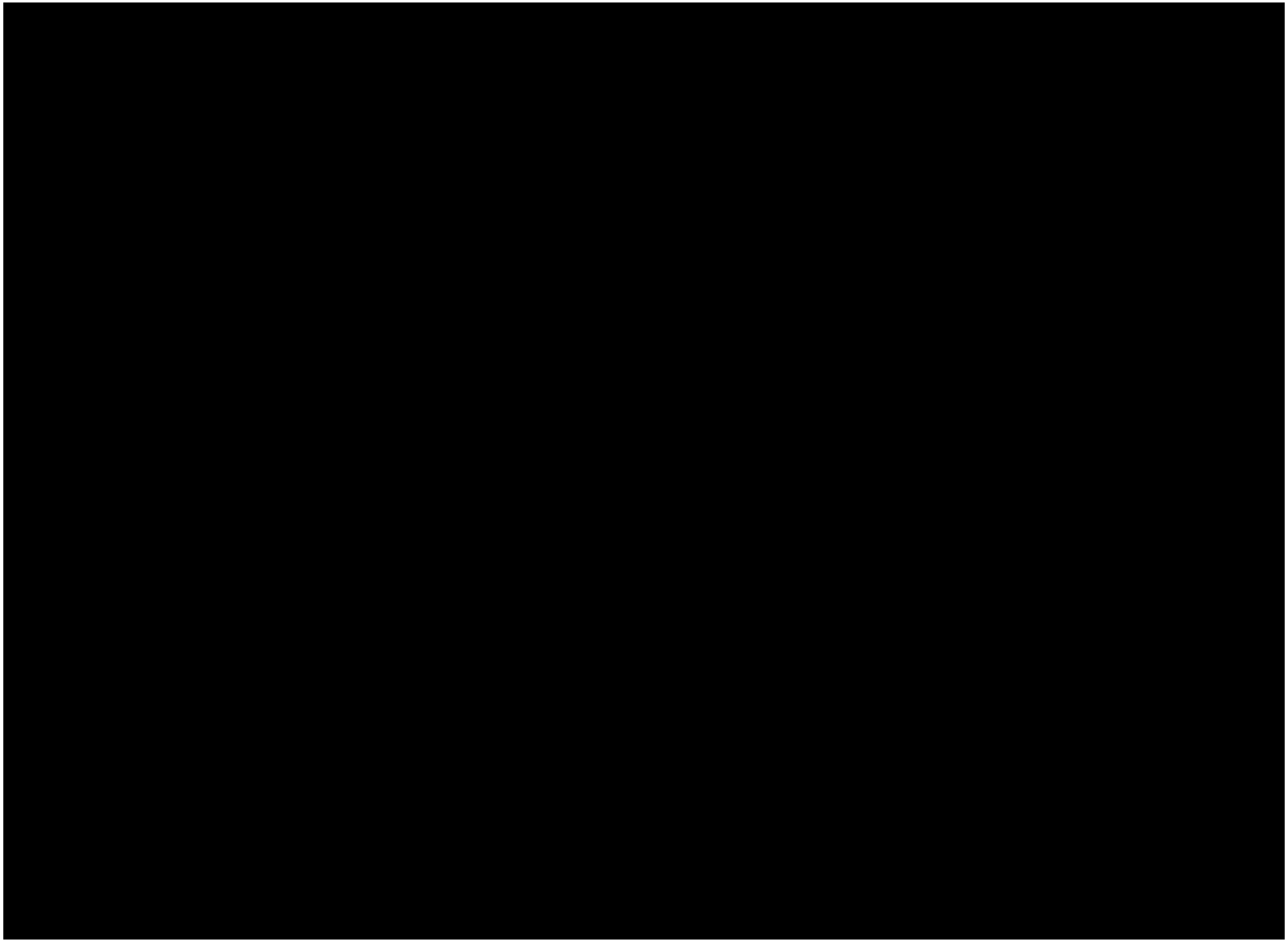
02/16/2018 Celestial calibration performed; Accuracy estimated to be within ~200milideg error – 0.15 beamwidth

03/02/2018 Automated operation of the JPL Ka-band ground station.

03/10/2018: During conical scan the peak of the beam demonstrates 33 dB gain, final L_0 requirement



Release from Dispenser



ISARA On-Orbit Gain Measurement

Ka-Band Payload

- >32 dB Reflectarray High Gain Antenna (HGA)
- 19 dB Standard Gain Antenna (SGA)
- Ka-band CW transmitter switches rapidly between SGA and HGA

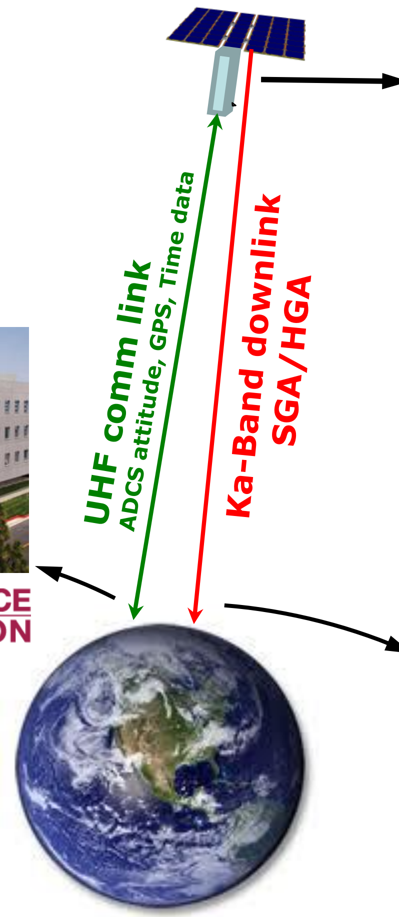
Gain Measurement

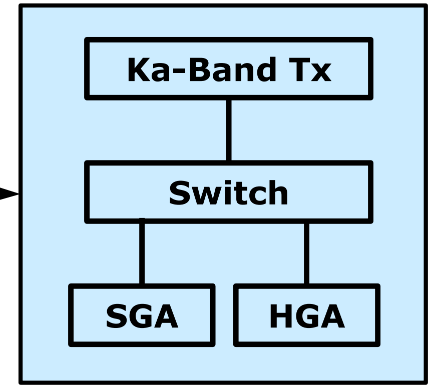
- Record received power P_{HGA}, P_{SGA}
- Calculate HGA gain:
  - Gain = $P_{HGA} - P_{SGA}$ + known SGA Gain

Key Advantages

- ***Eliminates key uncertainty factors:***
  - Transmit / receive line power losses
  - Space loss
  - Atmospheric loss
  - Ground station antenna pointing error
  - Minimize polarization mismatch loss
- ***Residual error can be estimated***
  - Receiver noise, SGA knowledge, etc.
    - Receiver noise is the main source
  - S/C antenna pointing (cause gain underestimate)
  - Directly calculate mean and variance

THE AEROSPACE CORPORATION





Ka-Band Receiver is JPL experimental ground station

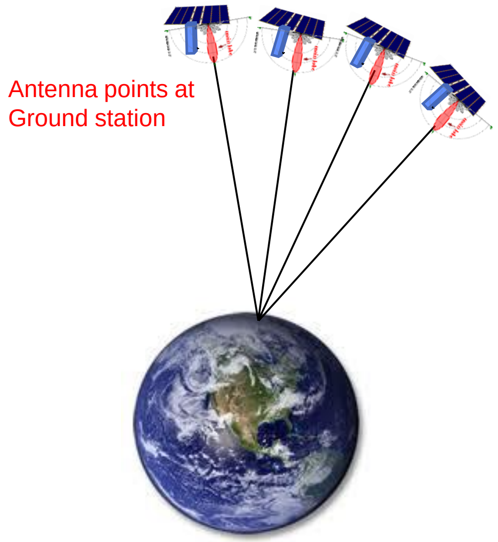
On-Orbit Experiment Overview

- ## ISARA Experimental Pass
  - Satellite in LEO orbit flies over ground station
    - **90 minute orbit – < 3 minutes per pass**
    - **Average one usable pass per day**
      - Limited by EPS-H power circuit failure & ground stations

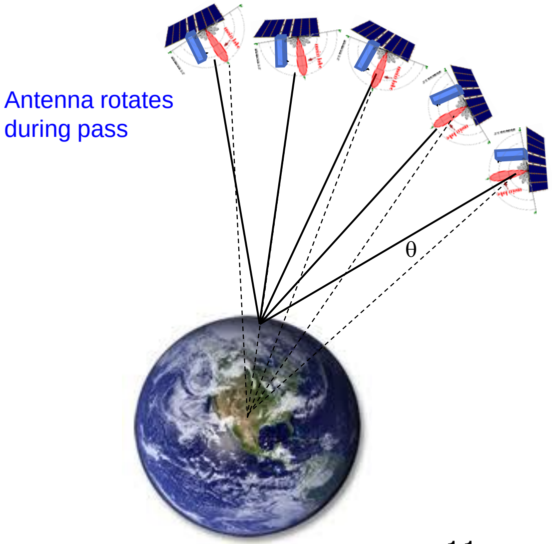
– ## Gain Measurement: HGA peak gain only
  - Aim antenna directly at ground station for entire pass
  - Large sampling rate – highest possible accuracy
  - Simulates conditions for an actual radio transmission

– ## Pattern Measurement & Beam Peak Search
  - <u>Conical Scan</u>
    - **Search for beam peak**
    - **Provides accurate *<u>minimum</u>* gain measurement**
  - <u>Principal Plane Patterns</u>
    - **Azimuth and Elevation pattern cuts**
    - **Very fine accuracy beam pointing data**

- ## Post Processing
  - Calculate pattern vs. angle in antenna coordinate system
    - **Use TAC telemetry data**



Gain Measurement



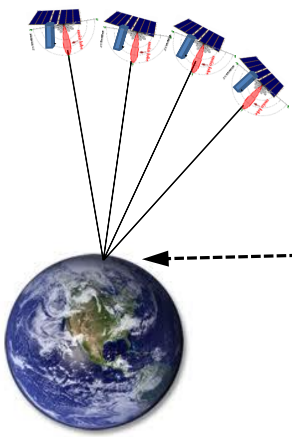
Pattern Measurement

Beam Search Algorithm

Select nominal beam peak direction, $\theta_{bx} = 0$, $\theta_{by} = 0$

Send pointing command θ_x, θ_y to s/c

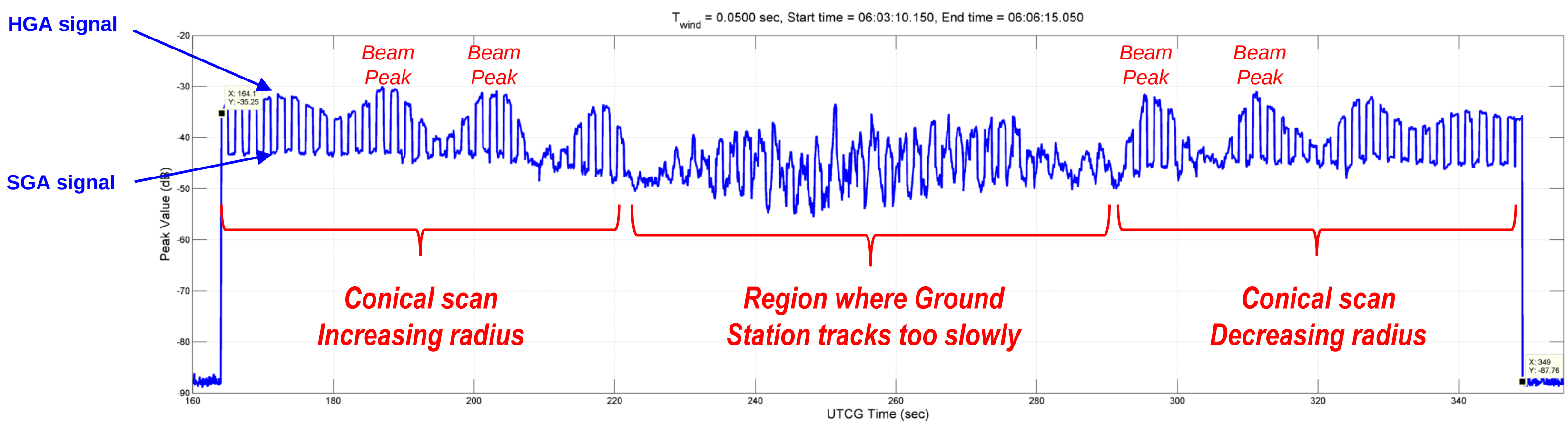
Perform conical scan (option: principal plane cut)



Data collection pass over JPL

Estimate pointing error $\Delta\theta_x$, $\Delta\theta_y$

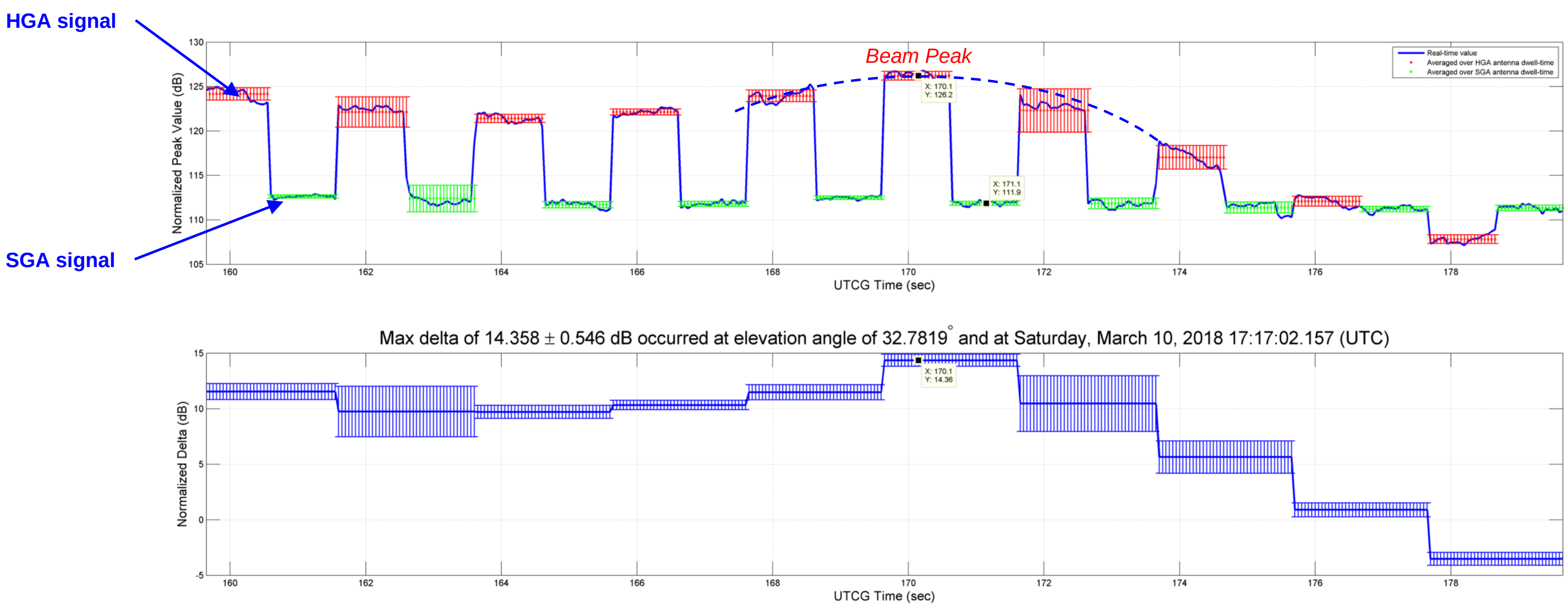
Estimate new beam peak pointing based on pointing data from several passes.



On-Orbit Gain Measurement

- Gain measurement by substitution method
  - Eliminates atmospheric loss, space attenuation, power level fluctuation, etc.
- Peak gain values taken from max signal observed in a conical scan pass
- Typical single pass signal shown below
- <u>Absolute</u> beam peak not yet confirmed

Gain Calculation	
HGA Signal Level	126.2
SGA Signal Level	111.9
Delta (HGA-SGA)	14.3
SGA Gain	18.9
Coax line loss delta	0.14
GAIN (on-orbit)	**33.4 dB**

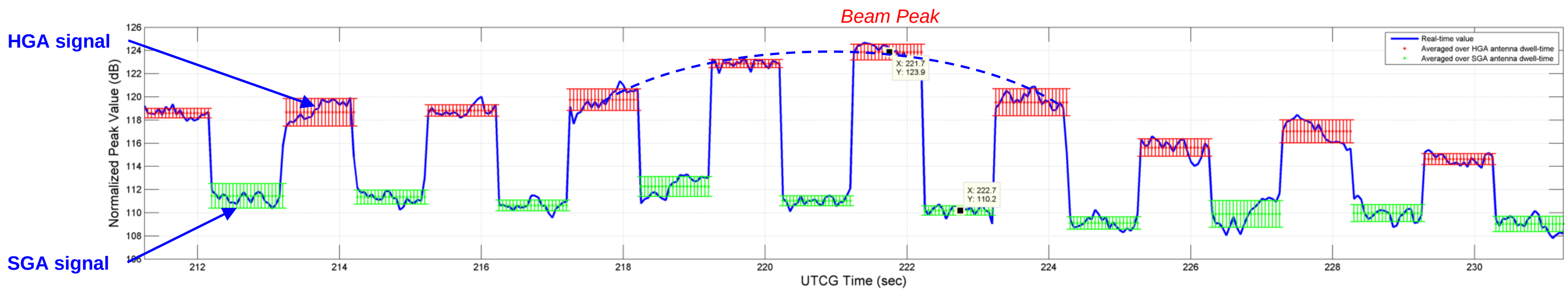


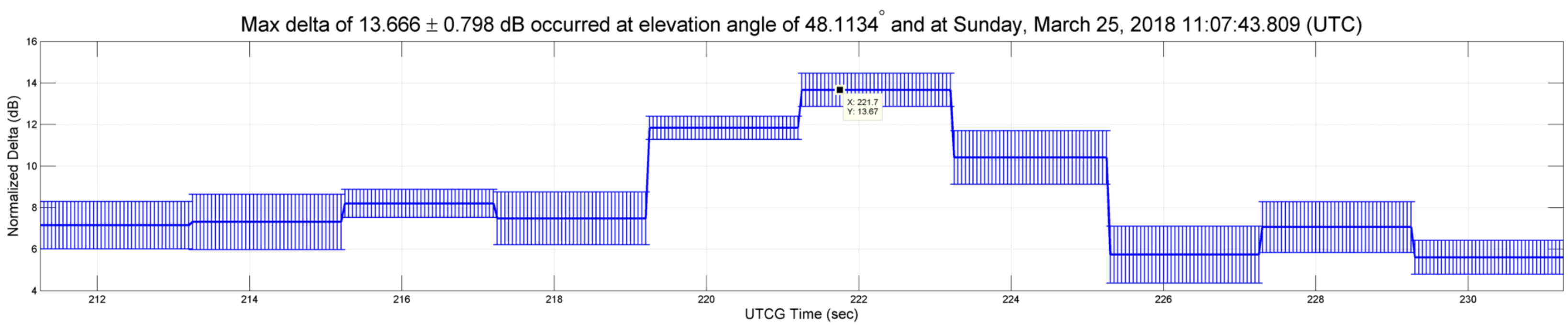
On-Orbit Gain Measurement Uncertainty

- Table at right shows uncertainty for several passes
  - Uncertainty is calculated on RMS averages taken over a pulse
- Some passes have noisy data – high uncertainty
  - Gain measurement pointing at ground station expected to give better results

Best Results Recorded

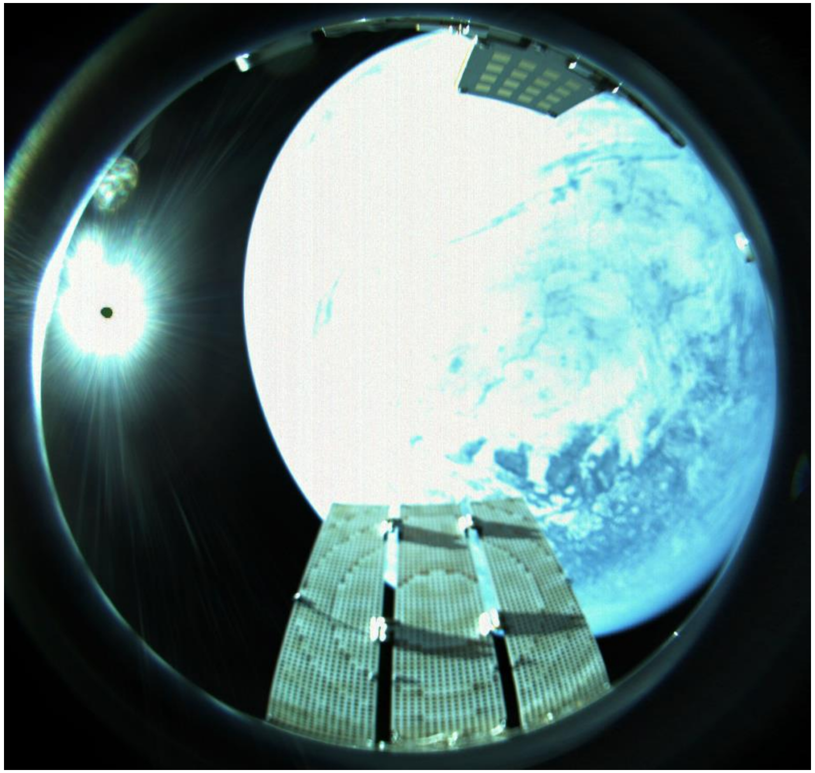
Date	Gain Measured (dB)	HGA-SGA Uncertainty (dB)	SGA Gain Uncertainty (dB)	Total Uncertainty (dB)
03/10/2018	**33.4**	±0.546	±0.25	**±0.60**
03/29/2018	**32.8**	± 1.036	±0.25	**±1.07**
03/25/2018	**32.6**	± 0.798	±0.25	**±0.84**





ISARA Technology Firsts

- ✓ First reflectarray antenna flown in space
- ✓ First high gain antenna integrated with solar panels
- ✓ First calibrated antenna gain and pattern measurement performed from space
- ✓ First 100 Mbps CubeSat telecom downlink capability



ISARA Reflectarray Deployed on Orbit

Fisheye lens photograph of the first reflectarray ever flown in space. Photograph taken by The Aerospace Corp. El Segundo, CA.

Next Generation – OMERA

One Meter ReflectArray

Requirements:

- Ka-band: 35.75 GHz
- Polarization: linear
- Dimensions: 98.6cm × 82.1cm
- Stowage volume: TBD
- F/D = 0.7
- Gain > 47.5 dBi
- S_{11} < -14dB